Nutrition, Illness, and Injury in Aquatic Sports

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In this review, we outline key principles for prevention of injury and illness in aquatic sports, detail the epidemiology of injury and illness in aquatic athletes at major international competitions and in training, and examine the relevant scientific evidence on nutrients for reducing the risk of illness and injury. Aquatic athletes are encouraged to consume a well-planned diet with sufficient calories, macronutrients (particularly carbohydrate and protein), and micronutrients (particularly iron, zinc, and vitamins A, D, E, B6, and B12) to maintain health and performance. Ingesting carbohydrate via sports drinks, gels, or sports foods during prolonged training sessions is beneficial in maintaining energy availability. Studies of foods or supplements containing plant polyphenols and selected strains of probiotic species are promising, but further research is required. In terms of injury, intake of vitamin D, protein, and total caloric intake, in combination with treatment and resistance training, promotes recovery back to full health and training.

Keywords: epidemiology, nutrition, swimming, infection, supplements, ergogenic aids

Aquatic coaches are obliged to use physically challenging training programs to prepare their athletes for high-level competitions. However, a high level of exposure to training (and competition) can increase the risk of illness or injury, limiting improvements in performance. Sports science and sports medicine practitioners who work with swimmers (and swimming coaches) are seeking effective evidence-based interventions and strategies to reduce the risk of injury and illness compromising training and competitive performance. Although the importance of illness and injuries and their impact on performance is better understood nowadays by both researchers and practitioners, there remains a lack of quality information, particularly related to the importance of nutrition and dietary practices.

Nutrient intake during everyday eating and around swimming training and competition is a key factor influencing immune function and risk of injury. Other factors related to illness include the volume, intensity, and load of exercise training; degree of exposure to pathogens; underlying health and medical status of individual athletes; lifestyle behaviors, including sleep and recovery; and psychosocial issues related to training and competition. Given the lack of specific research studies on highly trained swimmers, it is necessary to look more broadly at general nutrition, sports nutrition, and studies of athletes in other sports. A Medline search (November 2013) using nutrition as a search term yielded 325 hits for swimming, but only seven for water polo, six for long-distance swimming, five for diving, and two for synchronized swimming.

Although the benefits of avoiding illness and injury appear obvious, only one study has directly quantified the effect of illness on international swimming performance. A study of performances of Australian swimmers showed that mild illness had only a trivial mean effect on international performance by female swimmers and a small harmful mean effect on that of male swimmers. However, there were substantial chances of harm (and benefit) for individual swimmers reporting symptoms of illness (Pyne et al., 2005). More severe symptoms of illness that require medical intervention and complete cessation of training activities might have a larger effect on competitive swimming performance. In this review, we outline key principles of prevention for injury and illness in aquatic sports, detail the epidemiology of injury and illness of swimmers at major international competitions and in training, examine relevant scientific evidence on nutrients for reducing the risk of illness and injury, and summarize practical recommendations for swimmers, coaches, and practitioners.

Injury and Illness Prevention Principles

A perennial issue is establishing a rigorous evidence-based process for evaluating the effectiveness of training and lifestyle interventions in sports. Differences in definitions, terminology, and methodological approaches have made comparisons of research studies difficult. Effective
prevention of injuries and illness does not happen by itself and requires a systematic approach (Van Mechelen et al., 1992).

First, the problem must be identified and described in terms of incidence and severity. The objective of prevention of this problem is theoretically simple and can be summarized as removing the cause of injury or illness to prevent its occurrence. The second step identifies the factors and mechanisms that play a part in the occurrence of an injury or illness. The third step is to introduce measures that are likely to reduce the future risk or severity of injury or illness. These measures should be based on the etiological factors and mechanisms identified in the second step. Finally, the effectiveness of interventions must be evaluated by repeating the first step, yielding a so-called time-trend analysis of injury or illness patterns. However, from an epidemiological standpoint, it is preferable to evaluate the effect of preventive measures by means of a randomized controlled trial. Unfortunately, randomized controlled trials have only rarely been conducted in sports injury and illness prevention studies, let alone on the topic of nutrients and supplements. Most studies on this topic have been conducted in settings other than swimming. Accordingly, there is only limited scientific evidence on the value of preventive approaches to nutrients and supplements that can be directly applied to swimmers.

The underlying factors that lead to injury or illness are multifactorial in nature and may differ among athletes (Meeuwisse et al., 2007). Optimal prevention would imply an individualized approach to tackling risks and risk factors. At the elite level, an individual preventive approach with detailed analysis of individual risk factors is preferred. Any outcomes from (controlled) trials will be based on group estimates. Evidence from research studies alone should not be the foundation of effective injury prevention programs but is complementary to in-depth knowledge of an aquatic athlete’s health status. This type of pragmatic preventive approach should aid in the development and introduction of preventive measures for specific injuries or illness.

**Injury and Illness Prevalence in the Aquatic Disciplines**

The Fédération Internationale de Natation (FINA) began conducting injury and illness surveillance with the study of injuries in water polo in comparison with other team sports during the 2004 Olympic Games (Junge et al., 2006). The other disciplines of FINA, including swimming, diving, marathon swimming, and synchronized swimming, were added to the surveillance program in the 2008 Olympic Games (Junge et al., 2009). FINA conducted its first injury surveillance at the 2009 FINA World Championships (Mountjoy et al., 2010). Illnesses were also compared between aquatics and other Olympic sports at the 2012 Olympic Games (Engebretsen et al., 2013). FINA conducted its most recent injury and illness surveillance during the 2013 FINA World Championshipships, adding a retrospective survey of all athletes to quantify the incidence and characteristics of preexisting injuries (Mountjoy et al., in press).

In comparison with other team sports at the 2004 Olympic Games, water polo was safer than most other team sports, ranking sixth out of eight for the relative risk of injury. The total injury incidence was 12 injuries per 1,000 player matches (Junge et al., 2006). A study analyzing trends in water polo injuries in 2004, 2008, and 2009 showed that the overall injury incidence remained steady; however, significant differences were found in the incidence of gender-related injury (Mountjoy & Junge, 2011).

In the 2008 Olympic Games, swimming (3.4%), diving (2.1%), and synchronized swimming (1.9%) were among the group of sports with the lowest injury rates in comparison with other Olympic sports (mean injury rate = 9.6%). Water polo (9.7%) had one of the highest rates of in-competition injury and injury caused by contact. Swimming showed a high incidence of training and overuse injuries (Junge et al., 2009).

The 2009 FINA World Championships offered an opportunity to study the health of the aquatic athletes in more detail by including illness surveillance in the protocol. The overall injury rate was 6.6%, with only 0.8% of all injuries resulting in time loss. The overall illness rate was 7.1% with a 1.2% time loss. About half (50%) of these illneses affected the respiratory system, and 20% affected the gastrointestinal system. Infection was the leading cause (49%), followed by environmental factors (28%; Mountjoy et al., 2010).

On average for all sports, the injury rate in the 2012 Olympic Games was 12.9% and the illness rate was 7.2%. Swimming (5.4%) and diving (8.1%) were below the mean injury rate risk; water polo (13%) and synchronized swimming (14%) were higher. Diving had the highest incidence of overuse injury, with 76% of all injuries reported as having been caused by overuse. Synchronized swimming had one of the highest illness rates, at 13% of all athletes (Engebretsen et al., 2013).

A review of these surveillance studies showed that the aquatic sports have a relatively low risk of new-onset acute injuries during events. The most affected body location for injury is the shoulder, and the rates of overuse as a cause of injury in diving and swimming are high. Infectious illnesses of the respiratory and gastrointestinal systems also cause significant health concerns. This finding is consistent with experience in other elite sports (Spence et al., 2007). Knowledge of these trends in injury and illness patterns in aquatic sports enables effective prevention planning. The role of nutritional interventions for illness prevention and injury prevention and recovery warrant further development.

For example, asthma is a common airway disease present in the general population (Elers et al., 2011). A swimming program for asthmatic children has been shown to improve respiratory function and decrease the severity of asthma symptoms (Wang & Hung, 2009). The incidence of asthma in aquatic athletes at the 2008
Olympic Games was higher than in all other sport disciplines except for triathlon. Synchronized swimming has the highest incidence of asthma of all aquatic sports at 21%, followed by swimming at 19.3% (average 7.2%; unpublished Therapeutic Use Exemption data, IOC Medical Commission data). Antioxidant supplementation has proved effective in ameliorating asthma symptoms in nonathletes (Scott et al., 2013), and this approach may be worthwhile for swimmers.

**Review of Scientific Evidence for Nutrients**

A well-planned diet rich in nutrients is needed to maintain a robust immune system with sufficient capacity to tolerate the demands of training and competition. A swimmer’s diet should be sufficient to meet the underlying energy, carbohydrate (CHO), protein, and micronutrient requirements (Gleeson, 2013; Nieman, 2008) because energy availability has been demonstrated to be a key performance limiter in swimming speed (Vanheest et al., 2014). However, imbalanced nutrition in top-level swimmers is not uncommon (Kabasakalis et al., 2007). Younger swimmers who are maturing physically have additional dietary requirements to facilitate growth. Given that inadequate nutrition affects almost all aspects of the immune system, a well-planned diet is important (Gunzer et al., 2012). The most challenging energy demands for all aquatic athletes are the extended periods of training in the months before major competitions, such as a national championship or an international competition (FINA World Championships or Olympic Games). High-volume and high-intensity pool-based training generally characterize precompetition periods. Clinical trials or properly conducted randomized trials are difficult to conduct with elite athletes, including swimmers, and therefore research on dietary practices and nutritional supplements is somewhat inconclusive (Romeo et al., 2010).

**Caloric Intake**

Aquatic athletes may experience insufficient caloric intake either voluntarily when trying to manipulate body shape and composition or involuntarily in the face of physically demanding training. Although the aquatic disciplines may not have the body weight restrictions faced by athletes in other sports that emphasize leanness, some athletes experience energy and nutrient deficits. This situation is more relevant to synchronized swimming and diving, two sports in which the importance of aesthetic appearance is more prominent. The consequences of inadequate caloric intake may include compromised nutritional status, fatigue, dehydration, delayed growth, impaired tissue repair and immune function (Montero et al., 2002), menstrual dysfunction (Thein-Nissenbaum et al., 2011), higher psychological stress and risk of illness (Hagmar et al., 2013), and increased risk of injury (Thein-Nissenbaum et al., 2011).

A wide range of personal, lifestyle, cultural, socioeconomic, and religious factors can influence caloric intake. In the past decade, a concerted effort has been made to describe and manage dietary arrangements of Muslim athletes (including swimmers) during Ramadan, in which there must be abstinence from food and fluid intake from dawn to sunset for 1 month. Experienced elite Muslim athletes are able to maintain their usual training load during Ramadan without decrements in measures of fitness and with only minimal adverse effects (Mujuka et al., 2010). In addition to the provision of energy and specific nutrients, another issue is the effect of abstinence on inflammatory and immunological measures. However, it appears that athletes can train intensely during Ramadan without placing undue stress on the immune system (Chaoachichi et al., 2009).

Swimmers who voluntarily restrict caloric intake may invoke adverse effects on immunoglobulin and complement, both of which are key protein components of the innate immune system. An experimental group of athletes combining exercise and dietary restriction to invoke a mean weight loss of 2.8 kg exhibited small decreases in salivary immunoglobulin G and M and complement C3 concentrations 7 days after competition (Umeda et al., 2004). Although acute changes were small, the potential cumulative change over time might have more substantial effects on the immune system, thereby increasing the risk of illness. A study of female athletes in training showed that iron, vitamin B1, and niacin intake were positively correlated with immunoglobulin G levels (Kim et al., 2002).

**Carbohydrate**

CHO plays a key role in maintaining energy availability during training and competition, but also in homeostatic control of the hormonal and immune systems. It is well established that consuming CHO before and during exercise can attenuate the increases in glucocorticoid stress hormones such as cortisol. A swimmer training or competing in a CHO-depleted state may evoke a greater increase in the concentration of stress hormones and larger perturbation of key immune functions that may predispose them to illness (Gleeson & Bishop, 2000). A meta-analysis of 66 placebo-controlled or cross-over trials of nutritional interventions in athletes indicated the most effective choice was consumption of more than 6% CHO during prolonged exercise (Gunzer et al., 2012). Consuming 30–60 g of CHO/hr-1 using sports drinks, gels, or other sports foods during exercise should attenuate rises in stress hormones such as cortisol and limit the degree of exercise-induced immune depression. A 6-day CHO-rich diet (12 g CHO/kg body mass-1/day-1) during intensive exercise training maintained higher pretraining salivary immunoglobulin A concentrations and stabilized blood glucose concentration better than a control self-selected diet (Costa et al., 2005). Swimmers can be prone to fluctuating levels and higher variability in salivary immunoglobulin A concentration, which might...
reduce the level of protection against pathogenic agents at mucosal surfaces of the respiratory tract (Francis et al., 2005). Maintenance of glucose levels during training should attenuate cortisol release and reduce the risk of exercise-induced immunosuppressive effects. Finally, CHO supplementation can also reduce the symptoms of overtraining or overreaching (Halson et al., 2004) that sometimes accompany illness during periods of intensive work. Decreased endocrine responsiveness to exercise may be implicated in the decreased performance and increased mood disturbance characteristic of overtraining.

**Protein**

In the general population, moderate to severe deficiencies in dietary protein and selected micronutrients can lead to immune dysfunction and clinical consequences. Healthy aquatic athletes undertaking regular training and physical activity are unlikely to be suffering from protein malnutrition. However, a high-protein diet (3 g/kg-1 protein/day-1) might reduce the incidence of respiratory illness in at-risk athletes during periods of high-intensity training (Witard et al., 2013). Studies have investigated the benefits of coingestion of protein and CHO particularly in the recovery period after strenuous training or competition (Beelen et al., 2010). Coingestion of protein and amino acids does not seem to further increase muscle glycogen synthesis rates when CHO intake exceeds 1.2 g/kg-1/hr-1. However, from a practical point of view, it is not always feasible to ingest such large amounts of CHO. The combined ingestion of a small amount of protein (0.2–0.4 g/kg-1/hr-1) with some CHO (0.8 g/kg-1/hr-1) stimulates endogenous insulin release and yields similar muscle glycogen-repletion rates as ingestion of 1.2 g/kg-1/hr-1 CHO (Beelen et al., 2010). Studies are needed to investigate the immunological benefits of coingestion of protein and CHO.

Bovine colostrum supplementation could be a useful nutritional countermeasure to enhance (or maintain) immune function and reduce the risk of upper respiratory tract infection (URTI). Daily supplementation with bovine colostrum for several weeks can maintain intestinal barrier integrity and immune function and reduce the chances of URTI in athletes undertaking heavy training (Davison, 2012). The purported mechanisms are likely to relate in part to small bioactive components that survive digestion and are biologically available after consumption. One study investigating the effects of 12 weeks of colostrum supplementation showed a 79% increase in salivary immunoglobulin A concentration (Crooks et al., 2006).

Another dietary issue is celiac disease, with increasing diagnoses and public awareness in both the general community and sporting populations. Celiac disease occurs when the immune system reacts abnormally to gluten (a protein found in wheat, rye, and barley), causing damage to the small bowel. Celiac disease is not uncommon, with a prevalence of about 1 in 100 in the general community. Sports medicine practitioners working with swimmers should be alert to the possibility of celiac disease and familiar with the appropriate tests and diagnostic procedures (Mancini et al., 2011). The cornerstone of management of celiac disease is a gluten-free diet under the direction of a dietitian. Dietary issues related to celiac disease include poor absorption of iron, vitamin D, and calcium. There are substantial educational resources available for athletes on maintaining a gluten-free diet.

**Fat**

The immune system is sensitive to both fat intake and prolonged and intense exercise. A low-fat diet may compromise the immune system, whereas a higher fat diet may yield improvements, although the clinical effects remain unclear. Some athletes may consciously modify eating behaviors and consume as many as 25% fewer calories than actual energy requirements, leading to low intakes of some essential micronutrients and fats. Lipids are powerful mediators of the immune system and may play a role in modulating the immunosuppressive effects of strenuous exercise. A low-fat, high-CHO diet (i.e., of total calories, 15% fat, 65% CHO, and 20% protein) can increase proinflammatory and decrease anti-inflammatory cytokines, depress antioxidants, and negatively affect blood lipoprotein ratios (Venkatraman et al., 2000). Increasing total caloric intake by 25% to match energy expenditure and increasing dietary fat intake to 32% appears to reverse the negative effects of a low-fat diet on immune function and lipoprotein levels. Increasing the dietary fat intake of athletes to about 40% while maintaining caloric intake equal to expenditure does not negatively affect immune competency or blood lipoproteins, whereas it improves endurance exercise performance at 60%–80% of VO2max in cyclists, soldiers, and runners (Venkatraman et al., 2000). Studies are needed to determine whether the beneficial effects of higher fat diets in athletes, including long-distance and open-water swimmers, reduces the rate of common illnesses.

The effect of fish oil supplementation on the immune responses of elite swimmers was investigated in a randomized placebo-controlled trial. Swimmers received either fish oil capsules containing omega-3 long-chain polyunsaturated fatty acids or placebo for 6 weeks (Andrade et al., 2007). Fish oil elicited an increase in omega-3 fatty acids, a decrease in arachidonic omega-6 fatty acids in plasma, and reduced production of interferon gamma by cultured cells. A reduction in the production of tumor necrosis factor alpha was observed in both groups. Fish oil was able to attenuate the exercise-induced increases in prostaglandin E2. It appears that fish oil supplementation can influence exercise-associated immune responses in competitive swimmers.

**Vitamins and Minerals**

Despite the popularity of vitamin and mineral supplementation in both the general and sporting communities, the evidence of beneficial effects is limited, and the results
of relevant studies are often inconsistent (Gunzer et al., 2012). Most studies have indicated that vitamin and mineral concentrations are not usually a problem among athletes—notable exceptions may be calcium and iron in some female athletes. The clinical and performance issues associated with disordered eating in female adolescent swimmers may affect nutrient levels and body composition. Adolescent swimmers presenting with disordered eating had lower protein consumption and lower calcium intake than healthy eaters (da Costa et al., 2013). Suboptimal intake of vitamins and minerals can have a negative impact on health because vitamins A, D, E, B6, and B12 have important roles in immune function (Gleeson, 2013).

The issue of vitamin C supplementation remains controversial. The authoritative Cochrane Reviews concluded that the failure of vitamin C supplementation to reduce the incidence of common colds in the general population indicates that routine high-dose prophylaxis is not justified (Hemili & Chalker, 2013). However, in individuals exposed to brief periods of severe physical exercise, akin to the training and racing demands of elite swimmers, vitamin C supplementation could be worthwhile. Closer inspection of experimental evidence has indicated that vitamin C supplementation (1 g/day-1) might be beneficial in reducing the duration and severity, but not the frequency, of URTIs in male adolescent swimmers (Constantini et al., 2011).

The influence of vitamin D status on a variety of health and performance measures is a topical issue in the sporting community. A study of 225 endurance athletes during a 4-month winter period was undertaken to address this question (He et al., 2013). Low vitamin D status was associated with lower proinflammatory cytokine production by monocytes and lymphocytes. The proportion of subjects who presented with symptoms of URTI in the vitamin D–deficient group (plasma 25[OH]D < 30 nmol/L-1) during the study period was substantially higher than in the optimal vitamin D group (>120 nmol/L-1). Low vitamin D status could be an important determinant of URTI risk in endurance athletes. Mucosal as well as systemic immunity could be enhanced via vitamin D–dependent mechanisms.

Iron status and immune function can be impaired in various clinical conditions such as chronic inflammation and obesity. Iron is necessary for proper functioning of both the innate and the adaptive immune systems (Dao & Meydani, 2013). A study of healthy adolescent Greek swimmers reported substantial fluctuations of iron status during a training season but no significant differences in iron status or performance between iron-supplemented and nonsupplemented swimmers (Tsalis et al., 2004). In females, iron lost during the menstrual cycle could contribute to fatigue, illness, and performance decrements that can occur with a heavy period. However, screening for hematological and iron-related abnormalities in male athletes has a relatively low yield, and testing of both males and females is best performed on clinical grounds (Fallon, 2004).

There are conflicting recommendations on the use of zinc supplements for athletes, and no specific studies with swimmers. Zinc administered at a dose of 75–100 mg/day-1 within 24 hr of the onset of the common cold in healthy individuals (Singh & Das, 2013). For this reason, some practitioners support the use of zinc lozenges as part of an early intervention approach. Evidence for prophylactic use of zinc is lacking, and further studies are required. The purported side effects of zinc supplementation in some individuals include nausea, vomiting, diarrhea, metallic taste, and kidney and stomach problems; a health care professional should be consulted if these symptoms occur.

**Amino Acids**

Reduced glutathione can remove damaging reactive oxygen species such as hydrogen peroxide. Amino acid supplementation could increase intracellular glutamate and cysteine that consequently enhance concentrations of reduced glutathione (Newsholme et al., 2011). Branched-chain amino acid supplementation can reverse the reduction in serum glutamine concentration that occurs after prolonged exercise. Glutamine is the most abundant amino acid in the body and has a range of physiological roles, including with immune cells. A decrease in plasma glutamine can increase the risk of illness or infection mediated by lymphocyte responses and induction of cytokines, such as interleukin-1 and interleukin-2, tumor necrosis factor, and interferon gamma (Bassit et al., 2000). This study of illness in triathletes showed that those consuming branched-chain amino acid supplements (Bassit et al., 2000) were less likely to report illness. However, despite the purported benefits of glutamine, it is difficult to unconditionally recommend glutamine supplements for athletes (Newsholme et al., 2011).

**Plant Polyphenols**

Plant polyphenols such as quercetin are strong antioxidant and anti-inflammatory agents and exert antipathogenic and immunoregulatory influences. Studies on quercetin supplementation in athletes are suggestive of benefits in postexercise inflammation, oxidative stress, and immune dysfunction and reduction in rates of illness. Quercetin combined with other polyphenols and food components (e.g., green tea extract, isoquercetin, and fish oil) can induce substantial reductions in markers of inflammation and oxidative stress. Consumption of plant flavonoids, antioxidants, and omega-3 fatty acids elicited health benefits derived primarily through increased plasma antioxidant activity (McAnulty et al., 2011). A recent study examined the effect of a flavonoid-rich juice containing citrus juices and common vegetables on markers of inflammation, oxidative stress, and immunity in elite swimmers (Knab et al., 2013). Sprint and middle-distance swimmers had a small chronic elevation in markers of oxidative stress, exhibited minimal posttraining pertur-
bations in biomarkers, and received no apparent benefit from the juice apart from the underlying nutrient intake. Further work is required to establish clear guidelines for using combinations of supplements involving flavonols and flavonoid-rich juices.

Probiotics

Probiotics are live microorganisms that are present in some dairy foods and nutritional supplements that may prevent or limit the effects of various illnesses and infections. Probiotics complement the normal gastrointestinal flora and offer a practical means of enhancing gut and immune function (West et al., 2009). These bacteria are integral to the ontogeny and regulation of the human immune system, protection against infection, and maintenance of intestinal homeostasis. Some swimmers present with gut symptoms such as nausea, bloating, cramping, pain, and diarrhea. A small number of studies of highly active individuals have indicated modest clinical benefits of probiotics in terms of reduced frequency, severity, or duration of both respiratory and gastrointestinal illnesses (Pyne et al., 2013). To date, no studies have been published on probiotic supplemetations with swimmers.

Nutritional Recommendations for Injury and Illness Prevention

Illness Prevention

Illness prevention strategies center on limiting pathogen exposure, managing underlying medical issues, managing training load, and a variety of lifestyle and behavioral factors such as sleep, psychological issues, and nutrition (Gleeson, 2000; Pyne et al., 2000). Limiting pathogen exposure in the aquatic environment is important given evidence of water quality issues in swimming pools (McCann et al., 2013; Sanborn & Takaro, 2013) and freshwater and marine (Arnold et al., 2013) environments. Other factors influencing the risk of illness include season, with a higher risk of URTIs in winter months (Hellard et al., 2011).

In terms of nutrition, athletes should consume a well-balanced diet with sufficient calories, macronutrients (particularly CHO and protein), and micronutrients (particularly iron, zinc, and vitamins A, D, E, B6, and B12) to maintain health and performance. Ingesting CHO via drinks, gels, or sports foods during prolonged training sessions is beneficial. Recent nutritional studies have indicated benefits in consuming foods or supplements containing plant polyphenols and selected strains of probiotic species. Given the limited support from quality scientific studies for micronutrient supplementation, using a single nutrient may not be as effective as using a mixture of several nutritional supplements.

One perennial discussion point is whether the nutrient value and digestive processes of natural foods are preferred over consumption of commercially available nutritional supplements. Regular consumption of natural foods such as fruits and vegetables is seen as an important contributor to a healthy diet (Lamprecht, 2012). Plant foods are rich sources of vitamins, minerals, and phytochemicals. A deficit of these micronutrients could exacerbate inflammatory states, decrease immunity, increase susceptibility to injury, and prolong recovery from intensive training and competition. A combination of a well-balanced diet of natural foods and additional nutritional supplements on the basis of expert advice from a dietician or nutritionist is possibly the preferred approach.

Aquatic athletes need to be careful about sourcing and using nutritional supplements and ergogenic acids taken for dietary reasons or for convenience or to maintain or boost the immune system. Not all athletes need supplements. Many top-level athletes take no supplements at all, including successful Olympic and World Championship swimmers. These swimmers pride themselves on a high-performance diet, a good training ethic, and good sleep. Supplements should be taken only when swimmers are having difficulty meeting energy and nutritional requirements with their everyday diet. It is prudent action to avoid supplement companies involved in network marketing who are likely motivated by drivers other than training and competitive performance. It is difficult to absolutely guarantee the safety or legality of supplements, and swimmers should only use products from reputable companies and avoid supplements whose source or origin is uncertain. Supplements may contain World Anti-Doping Agency–prohibited contaminants that may trigger an adverse analytical finding during antidoping testing. Swimmers seeking nutritional information should be encouraged and reminded to seek expert medical opinion from a sports medicine practitioner or a registered dietician or nutritionist.

Long-term planning by organizations, teams, or individual swimmers should include a yearly sports medicine consultation, periodic contact with a sports dietician, review of primary and secondary vaccination schedules, advice on insect avoidance and malaria prevention, review of allergy and asthmatic conditions, establishment of a medical network, and management of team and travel logistics. Vitamin C and zinc supplements can be a useful addition to a so-called illness prevention or “sick pack” provided to some swimmers before long-haul travel, training camps, and major competitions (Hanstad et al., 2011). There should be a review or debriefing session after competition involving medical, scientific, and management staff; a written report of the medical events of the season, main competition, or both; referral of athletes experiencing long-term or recurrent or persistent illness for medical review; input from the dietician or nutritionist on team and individual swimmer issues; and early preparations for the following season.
Injury Prevention

An approach to injury prevention through nutrition follows a similar approach to that for illness prevention. Given that injuries are mainly due to mechanical stress and subsequent inadequate adaption of the musculoskeletal system, the role of nutrition in the onset of injury may appear trivial. However, at the elite level training loads are of such demand that appropriate levels of nutrients are required to provide the body with the building blocks to recover. Unfortunately, studies on the role of nutrition in the prevention of the onset of injury are in general lacking. Consequently, the potential role of nutrition in the prevention of injury has not been well described (Thein-Nissenbaum et al., 2011).

The best-described relationship between injury and nutritional status is that of vitamin D. Vitamin D is necessary for adequate bone health (Holick, 2004). It is plausible that suboptimal vitamin D status increases the risk not only of susceptibility to common URTIs and other illnesses but also of overuse and inflammatory injuries. The latter types of injuries are predominantly those suffered by aquatic athletes. Athletes participating in indoor sports, including aquatic sports, have been reported to have lower circulating vitamin D in the fall than athletes participating in outdoor sports (Halliday et al., 2011). These findings suggest that aquatic athletes are at increased risk for vitamin D insufficiency and deficiency and can have lower bone mineral density (Mudd et al., 2007). Although a full link between vitamin D insufficiency and injury has not been established as yet, studies of healthy individuals have indicated that vitamin D correlates positively with bone mineral density (Bischoff-Ferrari et al., 2006; Välimäki et al., 2004). Other studies have highlighted the causal link between low bone mineral density and the risk of stress fractures in athletes (Myburgh et al., 1990). Given these risks, adequate vitamin D levels are recommended to prevent injury in aquatic sports (Lewis et al., 2013). Care should be taken especially during fall and winter. It should be noted that vitamin D is limited in the general food supply. Only a few food products—including oily fish—naturally contain vitamin D. Other products that are fortified to contain additional vitamin D include milk, some fruit juices, margarine, and ready-to-eat cereals (Calvo et al., 2004). Additional intake of these foods and products by aquatic athletes is recommended, with additional supplemental intake during fall and winter.

It only seems logical and sensible that inadequate caloric intake may impair tissue repair (Montero et al., 2002). The question, however, of which type of calories are required to optimize tissue recovery remains unanswered. Also, the timing of caloric intake, the amount of (additional) caloric intake, and the form of intake require further study. A plethora of studies have looked at such questions from a performance perspective, that is, how to optimize functional recovery and training adaptation. Yet, the viewpoint of actual tissue repair and injury risk has mostly been neglected. As such, future studies are required on this specific topic.

A final consideration is the importance of nutrition when recovering from injury. Nutrient intake is important in wound healing and facilitating tissue repair in response to injury. Caloric intake might need adjustment if the athlete is not expending as much energy as usual when fully fit and in normal training and competition (Tipton 2013). Immobilization results in muscle loss resulting from increased periods of negative muscle protein balance as a function of decreased basal muscle protein synthesis and resistance to anabolic stimuli such as protein ingestion. Resistance exercise during the rehabilitation phase will increase muscle protein synthesis and restore sensitivity to anabolic stimuli. After initial injury management and treatment, the intake of protein and energy must be sufficient to support muscle growth.

Summary

• Aquatic athletes in all disciplines (i.e., swimming, water polo, synchronized swimming, diving, and open-water swimming) should benefit from a well-balanced diet to reduce the risk of illness and injury and promote rapid recovery back to full health and fitness.
• Evidence from experimental studies should always complement practical and clinical experience and in-depth knowledge of an aquatic athlete’s health status.
• Athletes should consume a well-balanced diet with sufficient calories, macronutrients (particularly CHO and protein), and micronutrients (particularly iron, zinc, and vitamins A, D, E, B6, and B12) to maintain health and performance.
• Evidence is emerging for the benefits of ingesting foods and supplements rich in polyphenols (flavonoids) and probiotics. More studies are required that evaluate the effectiveness of these nutrients and supplements in various sports-specific settings across the aquatic disciplines.
• Nutritional considerations for promoting tissue repair after injury center on overall caloric and protein intake. Vitamin D and ensuring balanced energy availability could be useful in a prophylactic approach to reduce the risk of injury (particularly related to bone health) and promote recovery from tissue damage.
• Aquatic athletes should have regular interaction with a sports dietician to develop and review specific nutritional strategies around training and competition. Particular care should be made around the selection, purchase, and consumption of supplements and ergogenic aids to limit the risk of contaminants and illegal substances.

Acknowledgments

The authors have no conflicts of interest to declare.
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